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Comparative study

The influence of surface angle on trunk muscle activity during Pilates based exercises

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1. Introduction

Pilates is a body conditioning format that consists of stretching and strengthening exercises developed to improve muscular control and postural stabilization (Brown, 1999). The exercises can be performed on a mat placed on a flat surface or on Pilates apparatus with the most common surfaces being the Cadilrlac, reformer and variations of the barrel and chair. In comparison to training on the floor, such apparatus are used to reduce the demands placed on the body (Latey, 2001). In the past two decades, Pilates has transcended recreational use to the clinical setting, highlighting its potential as a supplement to traditional treatment (Pata et al., 2013; Bryan and Hawson, 2003). Due to its ability to enhance the strength and endurance of trunk musculature, Pilates based exercises are often used to help treat musculoskeletal afflictions, such as chronic low back pain, and preliminary reports indicate benefits of Pilates during rehabilitation following a total knee or hip arthroplasty (Anderson and Spector, 2000; Gladwell et al., 2006; Lee, et al., 2014, Levine et al., 2009; Mostagi et al., 2015). Although each of the aforementioned studies differed in the Pilates and trunk exercises they examined, a common thread throughout their results was increased strength of the abdominal muscles.

Trunk musculature consists of the deep and superficial muscles that attach along the spine and the muscles within the abdominal wall and pelvic floor; proper activation of these muscles has been found to assist with spinal stabilization (Barr et al., 2005; Bliss and Teeple, 2005). Consequently, dysfunction within these muscles may promote the onset of musculoskeletal afflictions/postural injuries (Cholewicki et al., 2005). Electromyography (EMG) provides a useful tool in assessing differences in trunk muscle activation patterns between healthy versus injured populations during trunk exercises (Ng et al., 2002). Additionally, studies have demonstrated that Pilates based movements effectively target the muscles of abdominal wall and the spinal extensor muscles (Moon et al., 2015; Muscolino and Cipriani, 2004). Improved spinal stabilization, gained through the emphasis Pilates places on the trunk musculature to maintain posture and alignment, has been linked to training enhancements such as improved performance, decreased injury risk and reduced risk of injury reoccurrence (Sherry and Best, 2003; Phrompaet et al 2011; Butcher et al., 2007). Studies investigating back pain and common lower limb injuries have found evidence supporting the benefits of training to improve trunk strength and stability as a method of rehabilitation either in addition to or instead of only strengthening the muscles in the injured region (Sherry and Best, 2003; Zazulak et al., 2007; Gladwell et al., 2006).

Recent developments in the fitness and clinical industries have led to the introduction of new apparatus purporting to be useful for modifying the physiological demand and enhance training benefits if used while doing exercises. One such apparatus is an incline board which allows the individual flexibility to perform movements traditionally done on a flat surface at either an incline or decline angle; the retailer suggests that the board is ideal for a range of exercise formats including Pilates. Modifying surface angle is common practice in weightlifting and recent studies using traditional weightlifting movements, such as the bench press, have shown that altering surface angle from flat to incline or decline can modify muscle activation of the active muscles during the exercise (Lauver et al., 2015). The implication being that altering surface angle, and hence, muscular demand, for a particular lift may allow for a more complete and balanced muscular development.

Though surface angle modification is commonly practiced in weightlifting, it remains novel within Pilates. Herein we aim to examine how surface angle modification influences trunk muscle activity in Pilates by evaluating the effect of three different surface angles on trunk muscle activation during two common Pilates exercises.

2. Methodology

2.1. Participants

Nineteen young adults including 15 women (age = 25.14 ± 3.9 years, height = 1.61 ± 0.06 m, body mass = 52.39 ± 17.17 kg) and 4 men (age = 23.75 ± 5.05 years, height = 1.77 ± 0.07 m, body mass = 85.79 ± 14.58 kg) volunteered as subjects for the study. A power analysis calculation was used to calculate sample size, which determined that a minimum of 10 subjects would be required (Chow et al., 2008). Subjects were included if they were between

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the ages of 18 and 35, free from all metabolic, cardiovascular and orthopedic complications within the past year, and not currently engaging in any type of exercise more than twice per week. Due to the potential of balance challenges associated with using new equipment, only young adults were selected as subjects of this study. Upon meeting inclusion criteria subjects signed an informed consent form that was approved by the Institutional Review Board at Long Beach State University. To verify inclusion criteria, injury incidence and physical activity levels were determined based on self-reports by each subject.

2.2. Equipment

The flat surface exercises were performed on an exercise mat placed on the floor. The angled surface used was a 1.97 m long wooden board supported by a 0.50 m metal base to create an incline of 16.5° degrees. The board allows for support of the full body and the top of the board sits 0.56 m from the floor.

2.3. Data recording

All data collection took place in the Movement Science Laboratory at California State University, Long Beach. Surface electrodes were used, and to minimize crosstalk, the electrodes were placed onto skin that was cleansed with isopropyl alcohol wipes, shaved of excess body hair and secured to the skin with medical tape and a pre-wrap (Hermens et al., 2000; Konrad, 2006). Electrode pairs were placed over the muscle belly of the rectus abdominus (RA), 3 cm lateral and superior to the midline, the external obliques (EO), midway between the anterior superior iliac spine and the ribcage at the level of the umbilicus and the erector spinae (ES), 3.5 cm from the midline at the level of L2 and L4 vertebrae (Marshall and Murphy, 2003; McGill et al., 1996; Vera-Garcia et al., 2010). To maintain consistency between subjects, recordings were only taken from the muscles on the right side of the body (see Fig. 1).

Following the placement of the EMG sensors, the subject performed a maximum voluntary muscle contraction (MVIC) test for each muscle lasting for 5 s with a 30-s to 1-min rest in-between each muscle group. The MVIC was used to compare to the muscle activity recorded during the training session on the board and on the floor. The MVIC protocol followed has been previously established as an optimal method to obtain a maximal reading from these particular muscles (Vera-Garcia et al., 2010). To measure the EO, the participant performed an oblique crunch, with hips and knees flexed 90°, feet supported, and trunk maximally flexed and rotated to the left. A supine abdominal curl up was utilized to test the RA, with hips and knees flexed 90°, feet supported. Resistance was placed at the shoulders by an investigator pushing against the trunk for both abdominal MVICs. The Sorenson Test for back extensor strength without manual resistance was used to obtain a submaximal isometric contraction for the ES, equating approximately 40–52% MVIC (Demoulin et al., 2006). Verbal encouragement was provided during each MVIC; the investigator used the phrases “push”, “keep pushing” and “go” throughout the duration of the MVIC trial. Following the MVIC tests, the subjects was familiarized with the board by sitting, standing and walking in both the incline and decline directions.

2.4. Procedures

To determine the muscle activation differences of training on the floor in comparison to training on an angled surface, the movement order was identical on all surface angles, and subjects were randomly assigned to either perform on the board or the floor first. This assignment was determined based on subject order, so that odd numbered subjects performed on the board first, and even numbered subjects performed on the floor first. The exercises were performed for 10 s and repeated for three trials on each surface angle in one of two orders dependent on the starting surface; floor-incline-decline, or incline-decline-floor. The subjects received a visual demonstration of each movement prior to the first trial, and received feedback from the investigator throughout to ensure that proper form was maintained. If a subject was given more than two form corrections within one trial, the participant repeated the trial after receiving corrective feedback from the investigator.

Two isometric Pilates-based exercises of varying difficulty were selected: a high plank and a modified teaser, both of which are practiced in a typical Pilates class, and can safely be replicated on the elevated surface. These exercises were selected due to the limited safety concerns associated, the feasibility of the movements to be reproduced on varying surface angles, and to increase the validity of the muscle activity recordings when using surface EMG sensors (McBride et al., 2006). The benefits of these exercises have been previously established to utilize moderate to high levels of

Fig. 1. Placement of surface EMG electrodes on the EO and RA (LEFT) AND ES (RIGHT).

trunk muscle activity during movement execution, and useful to maintain and improve the strength and endurance of muscles within the abdominal wall (Ekstrom et al., 2007; Esco et al., 2004; Ni et al., 2014; Olson, 2013).

The high plank, referred to as the start of a pushup in Pilates, is a commonly used exercise often incorporated early in fitness or rehabilitation programs because it's beginner friendly due to its simplicity and ease of performance (see Fig. 2). The exercise has been associated to requiring muscle activity amplitudes related to endurance of the abdominals, particularly activation of the EO (Comfort et al., 2011; Jorgensen et al., 2010 & Ni et al., 2014). The traditional teaser pose is an advanced abdominal strengthening exercise common in both Yoga and Pilates and requires abdominal activation to resist torques created simultaneously by the trunk and lower limbs. The resistive torso torque, requires abdominal muscle activity to hold the position (Dias et al., 2014; Silva et al., 2013).

Movement execution of the exercises on the angled surface were set up slightly different in comparison to execution on the floor. During the high plank exercise, when on the incline and decline surface angles, the subject was instructed to grip the sides of the board rather than allowing wrist hyperextension caused by the angled surface (see Fig. 2). The teaser exercise was modified on all surfaces to reduce the torques placed on the spine by keeping the knees bent and the hands alongside the hips while in contact with the support surface, to reduce the difficulty of movement execution for non-regular exercisers (Salem et al., 2013; Wang et al., 2013). Subjects were instructed to start seated with hands and feet on the support surface with knees bent to 90°, the movement execution was obtained when the subject lifted the feet off the support surface while keeping the knees bent and simultaneously decreasing the horizontal angle of the torso to maintain balance (see Fig. 3). When performing on the board subjects were instructed to hold on to the sides of the board, and otherwise hands were placed on the on the floor (see Fig. 3).

2.5. Data processing and analysis

The EMG signals were collected at 1000 Hz and filtered in a

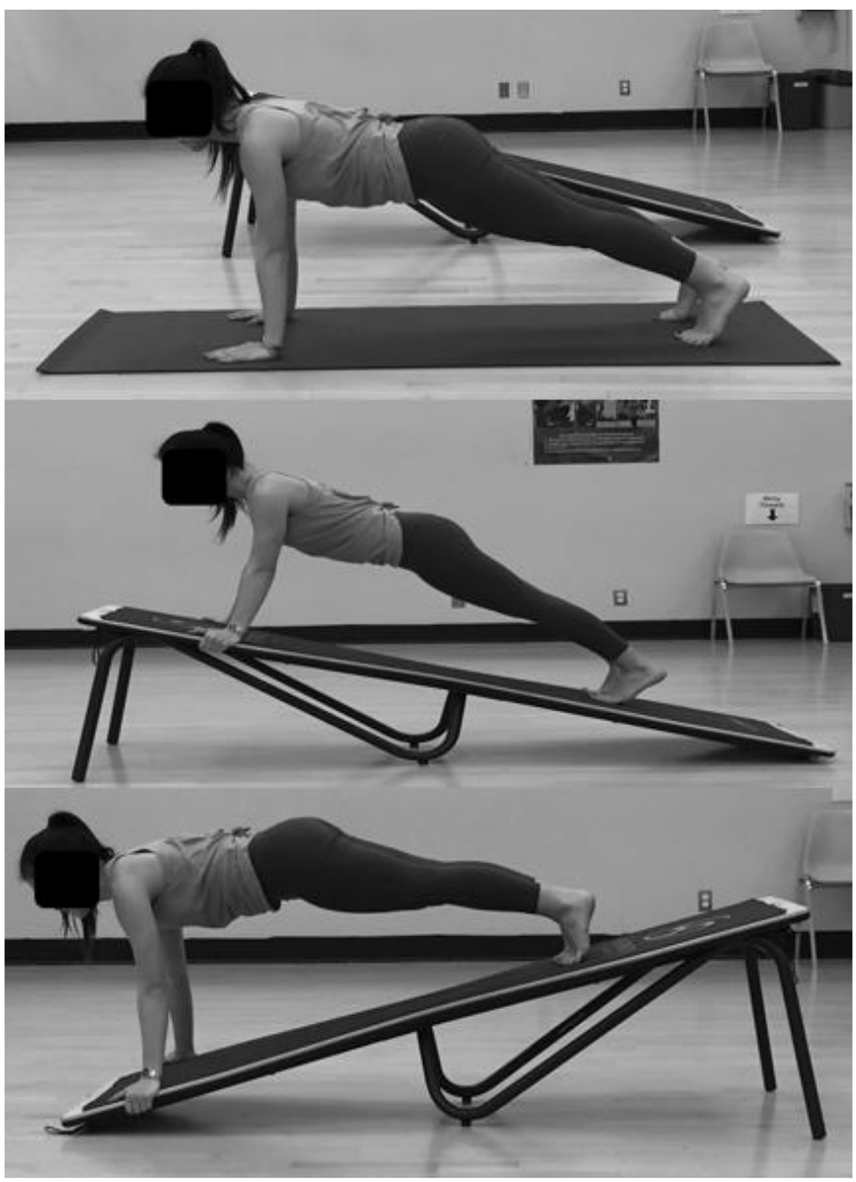

Fig. 2. High plank exercise executed on all three surface angles: floor (TOP), incline (MIDDLE), decline (BOTTOM).

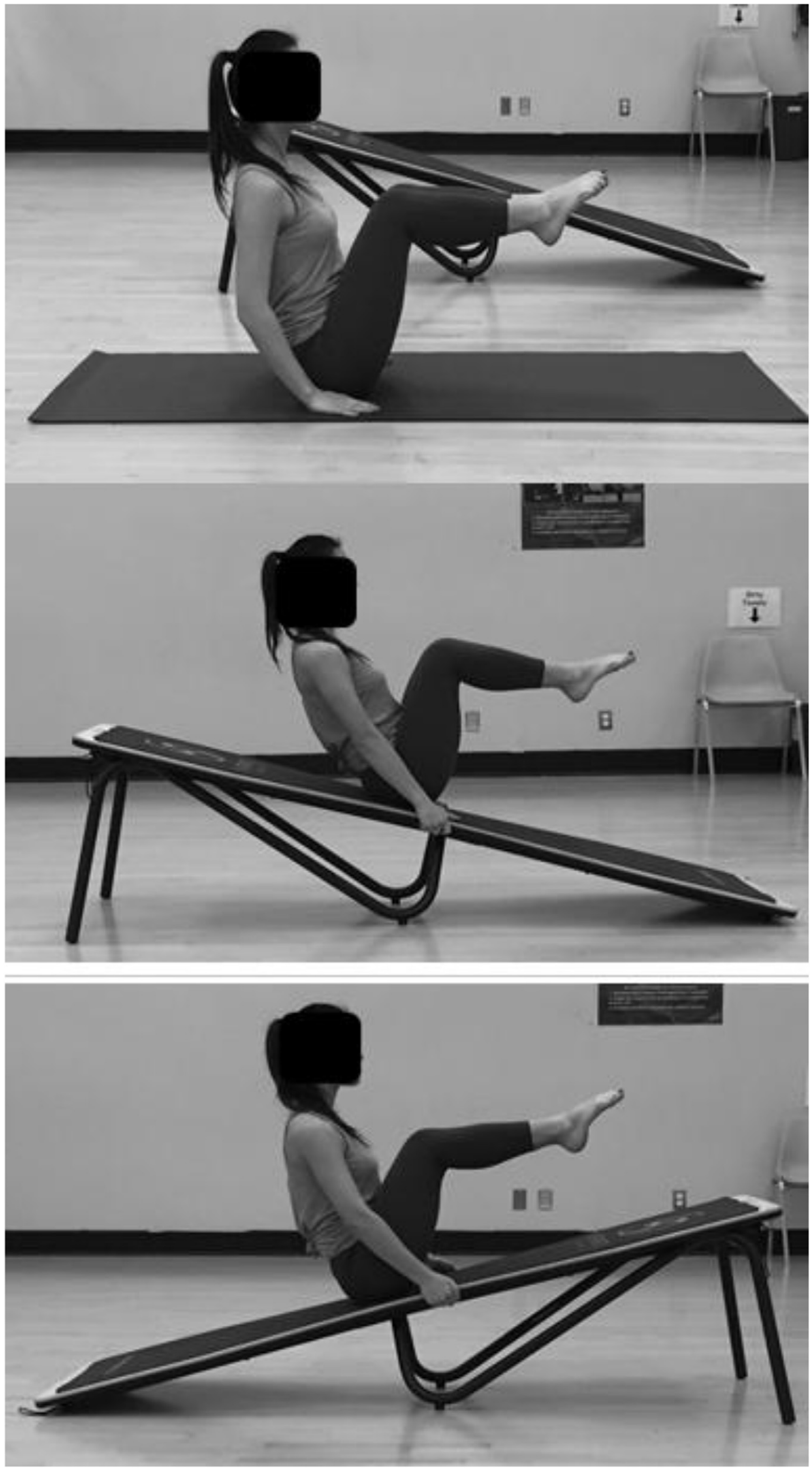

Fig. 3. Modified teaser exercise executed on all three surface angles: floor (TOP), incline (MIDDLE), decline (BOTTOM).

custom LabView program using a bandpass butterworth filter (40 Hz to 500hZ) to minimize crosstalk (Konrad, 2006). The peak 1-s of the MVIC trials and the middle 5 s of each exercise trial were processed to obtain the Root Mean Square (RMS) for each muscle. The average RMS for each muscle during the three exercise trials on each surface were normalized by the RMS of the MVIC for each muscle and expressed as a percentage of the MVIC.

A one-way repeated measures ANOVA was run for each muscle for both exercises to compare the activity between the three surface angles. A Bonferroni pairwise comparison was used to determine differences between surfaces within each muscle using an alpha level of 0.05.

3. Results

Table 1 shows the level of muscle activation as a percentage of the subject's MVIC required during the two different exercises. Previous studies have categorized muscle activity using the following relative muscle recruitment scale: <21% as low, 21–40% as moderate, 41–60% as high, and >60% as very high (Ekstrom et al., 2007; Escamilla et al 2010). The isometric exercises of this study did not require >60% MVIC, so the movements have been categorized into the first 3 levels only.

Normalized EMG values for the abdominal muscles during the high plank are shown in Fig. 4 as a % of MVIC. A significant increase in activity of the EO was evident during the decline plank (41.8% MVIC) in comparison to the floor (35.7%, $p = 0.015$) and incline (32%, $p = 0.018$) surfaces. In addition, the activity of the RA was significantly greater during the decline (32.3%) in comparison to the floor (25.2%, $p = 0.008$) and incline (24.5%, $p = 0.018$) plank. No differences were detected between the floor and incline surfaces for either abdominal muscle, or for the ES between any surface angle ($p > 0.05$).

Normalized muscle activity during the modified teaser pose (Fig. 5) varied for the RA between the three surface angles. The incline surface showed the greatest RA activity (47.7%) in comparison to the floor (28.6%, $p = 0.000$) and the decline (19.0%, $p = 0.000$). Differences in RA activation were also detected between the floor and decline ($p = 0.001$). EO activity varied less between surface angles, with the incline surface also eliciting the greatest amount of muscle activation (50%) and the decline producing the least amount of activity (38.3%). Differences were detected between the incline and decline surfaces ($p = 0.029$) and the between the decline and the floor (46.8%, $p = 0.014$). No differences were observed between the floor and the incline surface angles ($p > 0.05$). For the ES, the decline surface angle showed significantly lower muscle activity in comparison to the incline surface angle. No significant differences were seen between the floor and incline surface angles.

4. Discussion

This study investigated the influence of surface angle on trunk muscle (RA, EO & ES) activation during Pilates exercises. We demonstrate that: (1) decline high planks elicit greater RA and EO activity than flat and incline and (2) incline modified teaser induces greater RA and EO activity than flat and decline. For all surface angles and exercises, muscle activity of the spinal extensors (ES) was low (<13% submaximal activity). These findings support the use of an angled surface as a method of altering training demands placed on the abdominals, and of the limited role of the spinal extensors during exercises that promote abdominal strength or endurance (Lopez-Valenciano et al., 2013).

Establishing optimal training progression is crucial for exercise programs which aim to perpetuate gains in muscular strength and endurance (Garber et al., 2011). Exercise intensity, a key factor in exercise programming, must be altered over time to maximize muscular gains over time (Selye, 1955). For resistance exercises the load and/or volume can be used to quantify exercise intensity, but for body weight exercises intensity can be measured using force output or muscle activation (Baechle and Earle, 2008; Robertson et al., 2014). In the present study we utilized electromyography (EMG) to measure muscle activation, as a technique to quantify exercise intensity (Fukuda et al., 2010).

Our data reveal that during the high plank exercise, RA and EO activation was greater at the decline angle (32.3% and 41.8% respectively) than at the flat (25.2% and 35.73%) and incline (24.5% and 32.6%) surface angles. During the high plank exercise, the body position on the decline surface angle increased the moment arm of the trunk flexion torque about the vertical axis. This lead to an

Table 1
Relative muscle recruitment during the high plank and modified teaser.

	Surface Inclination	High(41-60% MVIC)	Moderate(21-40% MVIC)	Low(<21% MVIC)
Plank	Decline	EO	RA	ES
	Floor		EO,RA	ES
	Incline		EO	ES,RA
Modified Teaser	Decline		EO	ES,RA
	Floor	EO	RA	ES
	Incline	EO,RA		ES

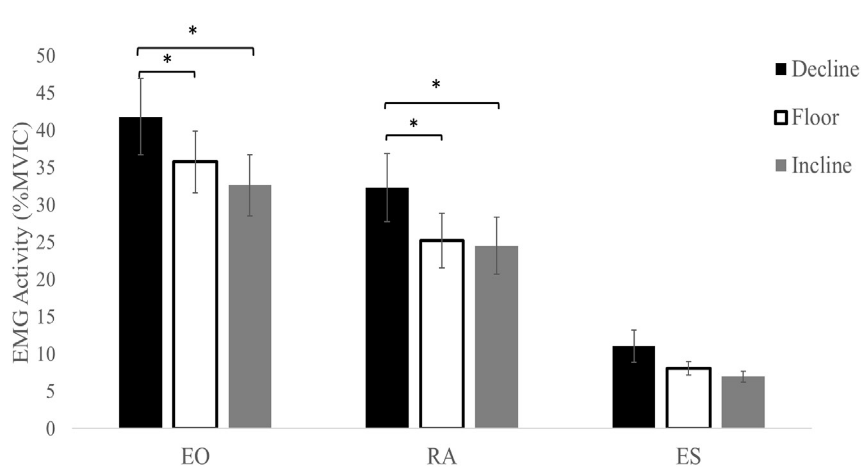

Fig. 4. Mean electromyographic activity as a percentage of MVIC for EO, RA and ES during the high plank exercise. Error bars represent SE. A * indicates $p < 0.05$.

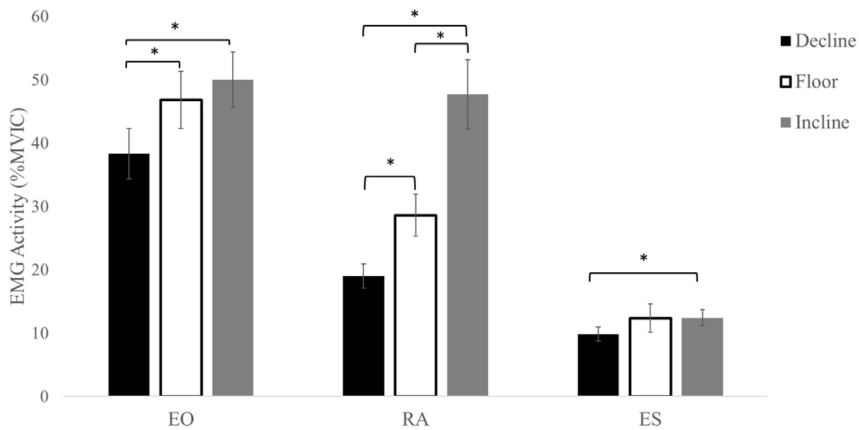

Fig. 5. Mean electromyographic activity as a percentage of MVIC for EO, RA and ES during the modified teaser exercise. Error bars represent standard error (SE). A * indicates $p < 0.05$.

increase in the activity of the primary trunk flexor, the RA, to meet these imposed demands (Lopez-Valenciano et al., 2013). The EO provides spinal stabilization and is a synergist to the RA during trunk flexion, which may explain the increase in its activity on the decline surface angle (Vera-Garcia et al., 2000). These findings are in line with Ebben et al. (2011) who measured ground reaction forces during pushups at varying body angles to quantify the load utilized by each muscle group at each angle. The authors reported that ground reaction forces were greatest on the decline angle and were decreased when on the floor and incline surface angles. Together, these results indicate that utilizing different body angles can be an effective method for progressing the intensity of body-weight training exercises on the abdominals.

The teaser pose is a more advanced abdominal strengthening movement that can be challenging when performed on a flat surface due to the simultaneous application of torques placed on the spine by the limbs and the trunk. Our findings highlight that varying the surface angle may either mitigate these challenges for less experienced individuals or intensify the movement for advanced individuals. While performing the teaser at the incline angle resulted in greater RA and EO activation (47.7% and 50% respectively) compared to the flat surface (28.6% and 46.8%), the decline angle significantly reduced RA and EO activation (19.0% and 38.3%) compared to both incline and flat.

During the teaser exercise, the activity of both abdominal muscles are required to maintain flexion of both the torso and the hips. More specifically, the RA serves as the primary trunk flexor with assistance from the EO. In addition, the lower EO fibers also contributes to spinal stabilization when the pelvis is pulled towards the rib cage during hip flexion, which is required during the teaser exercise (Dias et al., 2014). In our study, while hip flexion angles remained consistent throughout, the subject's pivot point on the surface and the horizontal torso angle shifted between surface angles. These kinematic changes altered the positioning of the pelvis and the trunk, and may have contributed to the changes in muscle activity. In comparison to the decline and floor surfaces, the incline surface angle shifted the pivot point superiorly along the pelvis (see Fig. 6). This raised the horizontal trunk angle, which increased the extensor torque, and hence, RA recruitment. Depending on the surface angle, the line of gravity either assisted or resisted the hip flexion torque, which may have resulted in the changing demands placed on the EO. When on the decline surface, the torque created by gravity promoted increased hip flexion, decreasing the demands placed on the EO. In contrast, when on the incline surface angle, the line of gravity created a hip extensor

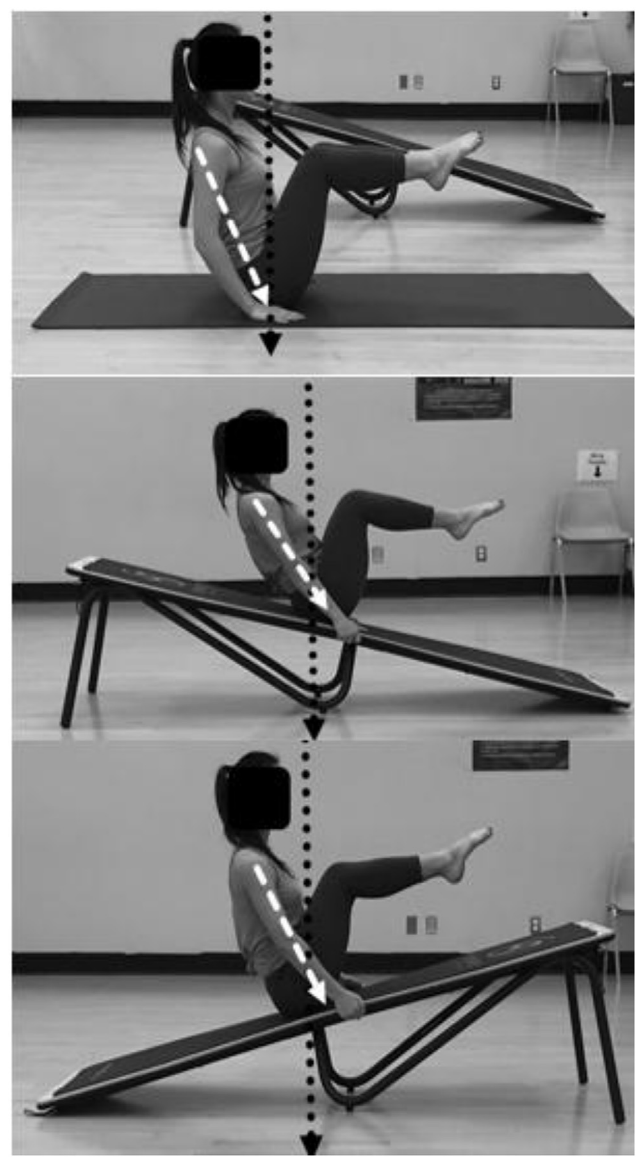

Fig. 6. Comparison of the line of gravity and trunk angles during the modified teaser exercise on the floor (TOP), incline (MIDDLE) and decline (BOTTOM).

torque which, in conjunction with the increased horizontal angle of the trunk, required a higher effort from the EO to maintain spinal flexion.

The results of the current study extend past findings regarding the influence of surface angle on muscle activation. Here, we show that changing the surface angle on which Pilates movements are performed can shift the degree to which trunk muscles such as the anterior and lateral abdominals are activated. Specifically, performing the high plank movement on a decline surface angle elicits greater EO and RA activation than flat or incline angles. Secondly, performing the teaser on an incline surface angle increases EO and RA activation compared to flat while the decline angle results in the lowest EO and RA activation of the three angles.

Trunk strengthening exercises are common in clinical settings, particularly for the treatment and prevention of reoccurring injuries. While Pilates-based exercises have been utilized regularly in therapy settings as a treatment for musculoskeletal injuries, only recently has scientific research been conducted to measure the perceived value. The results of this study may be useful for practitioners organizing exercise and treatment programs as way to increase or decrease exercise intensity, but it is important to keep in mind that movement execution will likely need to be modified in comparison to traditional Pilates movements. Altering the body position during the modified teaser exercise may elicit unintended effects that were unable to be captured by EMG. Clinicians should practice caution when performing seated exercises at an incline angle. Future research should focus on different Pilates-based and abdominal exercises while measuring additional musculature to further investigate the value of training at varying surface angles.

Possible limitations of the current study include: 1) the hand placement options while on the board, and 2) the lack of hip flexor measurement. Due to the incline of the board, hand placement needed to be altered for both exercises. During the plank, subjects were instructed to grip the sides of the board to prevent hyperextension at the wrist. This increased the subjects' base of support when on the board in comparison to the floor. During the modified teaser, subjects were also instructed to grip on to the sides of the board to minimize the risk of falling; hands were only placed on the floor when on the flat surface. Activation of the upper limbs was not measured, thus it remains unclear the extent to which upper limbs may have assisted. Examination of additional musculature, such as the hip flexors, may have provided additional insight into muscle activity patterns during the teaser exercise as this muscle group plays a role during spinal stabilization exercises.

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